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THE BARRIER FACTORS IN GIPSY MOTH TREE-BANDING MATERIAL.

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CONTENTS.

	Page.		Page.
Introductory and historical	1	Experimental work	3
Reasons for investigation	2	Summary and conclusions	14
The problem	2	Literature cited	15

INTRODUCTORY AND HISTORICAL.

Gipsy moth tree-banding material is a greasy and semiviscid substance, with an odor resembling that of tar, which is being used for tree-banding by the Bureau of Entomology in its control work against the gipsy moth (*Porthetria dispar* L.). It is a domestic product, originated in 1915, by members of the staff of the Bureau of Chemistry, United States Department of Agriculture, as a result of a request made by A. F. Burgess, in charge of the gipsy moth and brown-tail moth suppression work for the Bureau of Entomology. It was developed as a substitute for the German "raupenleim" (*1, p. 132*),[1] a product which had been in use, experimentally, in this country since 1891–92.[2] About that time it was brought to the attention of the gipsy moth authorities by Prof. B. E. Fernow, then Chief of the Division of Forestry, United States Department of Agriculture, who knew of its use against the gipsy and nun[3] moths and other insects in the European forests (*3, p. 129*).[4] The material closely resembles the raupenleim which it has now replaced. As manufactured at present, the gipsy moth tree-banding material is composed of coal-tar neutral oil,[5] hard coal-tar pitch, rosin oil, and ordinary commercial hydrated lime (*2, p. 3–4*).[6] The odor and the viscosity of the material, the characteristics or elements which are of chief concern here, become more pronounced with rising temperature, and in a warm and more or less confined atmos-

[1] Numbers in parentheses (italic) refer to "Literature cited," p. 15.
[2] Other importations were made in 1893 (*3, p. 129*), 1909, and 1912 (*1, p. 131–132*).
[3] *Liparis monacha* L.
[4] In Europe it has also been used to cover the egg masses of insects to prevent hatching (*3, p. 125; 4, p. 787*).
[5] A distillate substantially free from bases or phenols.
[6] For further details see U. S. Department of Agriculture Bulletin 899.

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phere, as in a room, the odor is quite pungent, irritating the mucous membrane to a considerable degree.[7]

REASONS FOR INVESTIGATION.

In the course of the preparation and use of the tree-banding material, as well as of the last of the raupenleim, by members of the gipsy moth force, the question as to what constitutes the barrier factor in the band arose; that is to say: What element or elements in the band halted the caterpillars in their attempted ascent to the foliage? Was it the exhalation, or odor (chemical property) of the material; or was it its softness, or viscidity (physical property)? Since the bands did not function as well in cooler weather or as they aged, was their decline in power or efficiency at such times due to their decreased viscosity, or firmer consistency; or was it due to the lessened odor? These questions had a practical bearing on the development of an efficient barrier, and attempts were made to obtain the desired information by means of field observations. These, however, were not successful; indeed, they served only to develop decided differences of opinion. Nor was there any help to be had from European sources. Mr. L. H. Worthley, for instance, who spent the summer of 1912 in Europe investigating gipsy moth conditions for the Bureau of Entomology, reported, on his return, that the forest authorities of Saxony and Bavaria regarded the odor as the effective element, or factor, in the band. But this information lacked applicability; for, aside from the fact that these foresters dealt exclusively with raupenleim, a material possessing a somewhat stronger or more pungent odor than the gipsy moth tree-banding material, their views were based largely, if not entirely, on the behavior of another species of insect, namely, the nun moth. It was possible, certainly conceivable, that the two species might differ in their reaction; and an investigation of the literature on the subject disclosed the propriety of the assumption, for, according to Judeich and Nitsche (*4, p. 845, 888*), such a difference of behavior exists, at least in the case of the nun and pine[8] moths, the caterpillars of the former, according to these authors, avoiding or shunning the raupenleim to a far higher degree than those of the latter. The uncertainty, it might be added, was somewhat further increased, in view of the further statement of Judeich and Nitsche (ibid.) that "Die Nonnenraupen vermeiden jede Berührung des Leimes * * *," by the statement of Ratzeburg (*9, p. 52*) to the effect that some of the caterpillars of the nun moth will brave the odor of tar. Because, therefore, of the lack of definite knowledge and the uncertainty and of the practical bearing that such knowledge had on the elaboration of an efficient barrier, it was deemed advisable to investigate the matter.

THE PROBLEM.

That the odor of the material exercises a restraining influence could not be doubted. Neither, on the other hand, could one with a

[7] The term "odor" is used here in the common or ordinary (and older) sense, inclusive of the irritating quality of the material as perceived by the nasal mucous membrane. Properly speaking, of course, the latter property of materials is not generally olfactory (*5, p. 165, 169*). In this connection the writer wishes to thank Prof. G. H. Parker, professor of zoology, Harvard University, for the courtesy of allowing him to read portions of his forthcoming book dealing with the chemical sense in vertebrates and for other suggestions.

[8] *Bombyx pini* L. ("der Kiefernspinner").

knowledge of the habits and behavior of insects and the action of banding materials in general doubt that the soft and semiviscid condition of the material acts as a bar. As it presented itself to the writer, therefore, the problem seemed to be really a matter of determining the relative values of the two factors; that is, which of the two is primary and will by itself constitute the effective, or the more effective, barrier against the gipsy moth caterpillars. As to procedure, the problem appeared to be a matter of devising a material with an odor like or very similar, and similar in degree of pungency, to the gipsy moth tree-banding material which would readily solidify or stiffen without materially losing in the process its odor-emitting quality, and this was to be used against the caterpillars in the form of firm or more or less solid, odorous bands, in connection with odorless check bands, both viscous and solid.

EXPERIMENTAL WORK.

The basal solid ingredient which suggested itself as possibly best meeting the requirements for such a material was ordinary white wheat flour. Flour is itself odorless, possesses the property of readily becoming firm, or of solidifying after being mixed with ordinary liquids, and is very easily obtained. Furthermore, it can very easily, by merely mixing with water, be made into a soft and somewhat pasty odorless material which can be utilized for check bands.

Accordingly, such flour[9] was mixed with coal-tar neutral oil or with a mixture of coal-tar pitch and coal-tar neutral oil, and placed in the form of bands on sheets of white paper laid on a horizontal surface and also around peeled upright wooden stakes. White paper and peeled stakes were used merely to facilitate observation. The caterpillars tested included all stages, beginning with the second. Soft and semiviscid odorless bands, made of flour and water, of flour and molasses, and of molasses alone, were used as checks.

In summarizing the results of these tests, it may be said that the stiff or solid odorous bands, while exercising a repellent and restraining influence to a considerable degree, proved no absolute bar to the caterpillars. The soft and semiviscid odorless bands, on the other hand, were never crossed, although they were approached with far less hesitation and were, on the whole, touched more often and were even eaten. The bands on the horizontal surface were crossed more readily than those placed in the form of rings on the upright stakes, and, in general, the bands were less effective against the larger or more advanced stages of the caterpillars. The latter statement applies more particularly to the horizontal bands. The caterpillars—the larger ones in particular—seemed to have some difficulty in maintaining a "foothold" on the bands on the stakes, but this seems to have been due, in part at least, to the yielding and somewhat friable nature of the bands.

SERIES I.

The following illustrations, taken from numerous experiments or tests, will show in a detailed way the behavior of the caterpillars with reference to the stiff or solid odorous band series.

[9] Putty, as a substitute for flour, was later also used but proved less satisfactory.

EXPERIMENT A.

(Day dull and rather cool.)

ELEMENTS.

Caterpillar.

Fourth stage; not very far advanced, rather small for the stage.

Bands (horizontal).[10]

1. Flour paste band made of wheat flour and water, about $\frac{1}{16}$ inch high, $1\frac{1}{4}$ inches wide, $5\frac{1}{2}$ inches long. **2.** Solid band made of flour and water (hardened), $\frac{1}{8}$ inch high, $1\frac{1}{4}$ inches wide, 6 inches long, sides practically vertical. **3.** Solid band made of flour and coal-tar neutral oil (at rate of $1\frac{3}{4}$ ounces flour and $\frac{5}{8}$+ ounce oil), $\frac{1}{8}$ inch high, $1\frac{1}{2}$ inches wide, $5\frac{1}{4}$ inches long. **4.** Solid band made of flour and coal-tar neutral oil (at rate of 2 ounces flour and 1+ ounce oil), $\frac{3}{16}$ inch high, $1\frac{1}{16}$ inches wide, $4\frac{1}{2}$ inches long, sides vertical. **5.** Solid band made of flour and coal-tar neutral oil (at rate of 2 ounces flour and $1\frac{1}{2}$ ounces oil), about $\frac{1}{4}$ inch high, $1\frac{1}{16}$ inches wide, and $5\frac{1}{4}$ inches long, sides vertical.

All on sheets of white paper.

TESTS.

Band 1: 9.25 a. m.

The caterpillar was placed five distinct times on the sheet of paper 6 inches from and facing the band, and during about one-half hour made 16 attempts to cross the band, but backed out or turned away each time it came more or less in contact with the band.

Band 2: 9.55 a. m.

The caterpillar was placed twice 6 inches from the band, and *crossed each time* without very much hesitation.

Band 3, *with marked coal-tar neutral oil odor,* somewhat damp to touch: 10.25 a. m.

The caterpillar was placed 6 inches from and facing the band. It approached within 2 inches of the band, then turned at an angle and went around the end of the band.

The caterpillar was placed again in the same position. It stopped short and turned somewhat at an angle when about 2 inches from the band but soon resumed a straight course, swung upon the band on reaching it, and *crawled across.*

The caterpillar was placed a third time. It stopped short and turned away from the band when within about $\frac{1}{8}$ inch of it and after crawling along it for a short distance, about $\frac{1}{4}$ inch away from it, it veered abruptly and crawled away.

Placed a fourth time, the caterpillar stopped and swung its head three times when about $\frac{1}{4}$ inch from the band, then continued, and on reaching the band (at a slight angle) it swung upon it with the first pair of legs, but after lingering on the band 2 or 3 seconds it swung off and crawled away.

Band 4, *with marked odor,* somewhat damp to touch: 11 a. m.

The caterpillar was placed 6 inches from and facing the band. It paused when about $4\frac{1}{2}$ inches away and again at a distance of about $\frac{1}{4}$ inch and swung its head two or three times; stretched forward when about $\frac{1}{8}$ inch away and apparently came in contact with the band; then turned and crawled away.

The caterpillar was placed again. It paused when about $2\frac{1}{8}$ inches away and again at about $\frac{1}{8}$ inch, then stretched toward the band and after some hesitation swung upon it (with the first pair of legs) and *hesitatingly crawled up and across.*

When placed a third time, the caterpillar got to within about $\frac{1}{8}$ inch of the band, swung its head several times, turned and crawled away.

Placed for the fourth time, the caterpillar approached within about $\frac{1}{16}$ inch of the band and turned away, but soon swung back, and after getting upon the band with the first pair of legs, swung down and crawled away.

Being placed for the fifth time, the caterpillar stopped about $\frac{1}{8}$ inch from the band and swung its head two or three times, then resumed, and on reaching the band presently at a slight angle, it swung on with the first pair of legs,

[10] The gipsy moth tree-banding material band used on trees in the control work against the gipsy moth is $1\frac{1}{8}$ inch wide and $\frac{3}{32}$ inch thick, and is rectangular in form (*2, p. 10*).

but swung down almost immediately. It turned toward the band again, however, after crawling along it for a short distance, about ¼ inch away, and, on reaching it, swung on a second time and hesitatingly *crawled up and across.*

Band 5, *odor quite marked,* somewhat damp to touch: 11.40 a. m.

The caterpillar was placed 6 inches from and facing the band. It hesitated when about ⅛ inch from it, then went to it and swung on with two pairs of legs, but swung down after lingering on it a few moments. Then it moved along the band nearly to the end, at a distance of about ¼ inch, when it suddenly swung away still farther and crawled away.

Placed again, the caterpillar turned out of a straight course slightly, when about ⅛ inch from the band, and again when about ⅛ inch away; it then stretched toward the band and brushed it with its mouth parts, following which it swung away and crawled off the sheet of paper.

The caterpillar was placed a third time. It paused when within ⅛ inch of the band, then moved closer, swung on with two pairs of legs, and brushed the band with its mouth parts three times in succession. Then it swung down and crawled away.

Placed the fourth time, the caterpillar turned at right angles when about ¼ inch from the band and crawled away.

When placed the fifth time, the caterpillar approached within about ⅛ inch of the band, hesitated, stretched forward, and got on the band with the first pair of legs. After getting on a little farther, it swung off and crawled away—11.50 a. m.

For the sixth time the caterpillar was placed (1.25 p. m.). It turned when close to the band and crawled away.

At the seventh placing the caterpillar swung upon the band with the first pair of legs, then swung off; soon after it swung up with two pairs and swung off, but very soon after swung on a third time and *crawled hesitatingly across.*

EXPERIMENT B.

(Day more or less bright and fairly warm.)

ELEMENTS.

Caterpillar.

Fifth stage; quite well along, fairly large.

Bands (horizontal).

1. Flour paste band made of flour and water, 1/16 to 1/12 inch high, 1¼ inches wide, 6 inches long. **2.** Solid band made of flour and water (hardened), ¼ inch high, 1½ inches wide, 6 inches long, sides practically vertical. **3.** Solid band made of flour and a mixture of coal-tar pitch and coal-tar neutral oil (at the rate of 2 ounces flour and 1½ ounces pitch and oil mixture), ¼ to 5/16 inch high, about 1½ inches wide, 5 inches long, sides vertical.

All on sheets of white paper.

TESTS.

Band 1: 2.35 p. m.

The caterpillar was placed nine distinct times on the sheet of paper, 5 inches from and facing the band. During the course of 42 minutes it made 15 attempts to cross the band, but backed out or turned away each time it came more or less in contact with it.

Band 2: 3.25 p. m.

The caterpillar was placed 5 inches from the band, as in the preceding test. It turned at an angle when about 2 inches from the band and crawled around the end.

The caterpillar was placed again. It swung upon the band with the first pair of legs and after some slight hesitation *crawled up and then across.*

Placed a third time, the caterpillar turned out of a straight course somewhat when about 3 inches from the band; then got to the band and touched it with its mouth parts several times in quick succession; *then crawled up slowly and across.*

Band 3, *with strong odor,* somewhat damp to touch: 4.15 p. m.

The caterpillar was placed 5 inches from the band, as before. It turned away slightly on reaching and touching the band with its mouth parts three or four times in rapid succession, but soon turned back and, after touching it as before, turned and crawled away, shaking its head nervously.

The caterpillar was placed again. It paused and shook its head when about ½ inch from the band, then hesitatingly and nervously moved to the band and touched it lightly with its mouth parts two or three times in rapid succession, brushed it with two pairs of legs, and turned away. It turned toward the band again, however, soon after, and swung up to the top with two pairs of legs, but after touching it with its mouth parts and swinging its head several times it swung down and crawled away.

Placed a third time, the caterpillar hesitated about ¼ inch away, then moved to the band and after touching it with its mouth parts lightly and brushing it with two pairs of legs, swung down. It repeated this shortly after and crawled away.

Placed a fourth time, the caterpillar began to hesitate when about ¾ inch from the band, but finally reached it and continuing hesitatingly *crawled up and across*, swinging its head constantly while on the band.

The caterpillar was placed a fifth time. It swung upon the side of the band with its first pair or two pairs of legs and touched it lightly and rapidly with its mouth parts two or three times and swung down, but soon afterwards it moved toward the band again and after a slight pause swung up a second time (with two pairs of legs). After a few moments it started to swing off, but swung back almost immediately and after some further hesitation crawled up *and then across*—4.45 p. m.

EXPERIMENT C.

(Day bright and warm.)

ELEMENTS.

Caterpillar.

Fourth stage; fairly well along, medium size for the stage.

Bands (rings on stakes).

1. Flour paste band made of flour and water, 1¼ inches wide, $\frac{1}{16}$ inch thick. **2.** Solid band made of flour and water (hardened), 2 inches wide, ½ to ⅝ inch thick, bottom plane nearly flat. **3.** Solid band made of flour and coal-tar neutral oil (at rate of 2 ounces flour and 1 ounce oil), 1⅛ inches wide, $\frac{3}{16}$+ inch thick, bottom plane practically flat.

All on peeled upright stakes, 20 inches high and about 2½ inches in circumference, lower edge of bands about 8½ inches from platform to which stakes were fixed.

TESTS.

Band 1: 1.45 p. m.

The caterpillar crawled up each of the four distinct times that it was placed at the base of and facing the stake, and during the course of 35 minutes made 40 attempts to cross the band, but backed out or turned away each time it came more or less in contact with it.

Band 2: 2.45 p. m.

The caterpillar was placed twice at the foot of the stake, as before. It crawled up *and crossed* the band without hesitation each time.

Band 3, *with marked odor:* 3.20 p. m.

The caterpillar was placed at the foot of the stake, as before. It seemed to hesitate slightly about ½ inch below the band, but with that exception moved right up to the band and paused; then, after crawling somewhat, swung upon the band and started upward. It progressed slowly, however, and when on with the anterior half of the body fell over backward, but clung to the stake with the last pair of prolegs. On swinging back to the band it resumed its upward climb. As before, its progress was slow; it was constantly working its legs and mouth parts and constantly applying the latter to the band, scratching up the surface. It persevered, however, and finally *crossed the band*, coming to rest about 1½ inches above it. Nearly two minutes was occupied in crossing.

The caterpillar was placed again. It crawled up slowly, came to rest about one-half inch below the band, and did not become active again for about four minutes, when it swung its head two or three times and moved up to within one-third inch. Here it rested for two minutes, and on being touched at the anal end with a small camel's-hair brush started upward again. On reaching the band it swung upon it with the first pair of legs, but after touching it with its mouth parts a number of times in rapid succession it swung off. It swung up a second time soon afterwards and swung down again after behaving as

above. Very soon after it swung on a third time, but after touching the band with its mouth parts several times in quick succession, as before, it swung down again and came to rest about 1½ inches below the band. It remained thus for four minutes, when, following application of the brush to the anal end, it turned round and crawled down the stake.

Placed a third time, the caterpillar paused and turned out of a straight course about one-fourth inch below the band and on reaching it swung upon it with the first pair of legs. It turned downward on swinging off and came to rest with its head about 2 inches below the band. It fell off the stake a few minutes later when its anal end was touched with the brush.

Placed once more, the caterpillar came to rest about two-thirds inch below the band. On being touched with the brush, about two minutes later, it moved up to within one-half inch and became motionless again, remaining thus for several minutes, except for swinging its head three times. It became active again on being touched once more with the brush, and on reaching the band it swung on with the first pair of legs. After swinging off and crawling somewhat, it swung on and off a second time. It swung on and off a third time soon after, and immediately afterwards swung on a fourth time, and continuing upward worked its way up, by degrees, *and across*—4.10 p. m. It took it a minute to cross.

In both instances, in which the band was crossed, the crossing was accomplished by a pawing-like motion of the legs and constant motion of the mouth parts, and by the continual application of the latter to the band.

Well defined as were the results of this series of tests, of which the above are examples, they were nevertheless not altogether satisfying. The fact is that the solid odorous bands, though strongly charged with odor, were not—and could not be made—as strong in this respect as the gipsy moth tree-banding material bands, owing to the limited capacity of the flour to absorb and to hold the liquid banding material ingredients. The results were indicative, indeed, but hardly conclusive.

SERIES II.

To obtain more conclusive results, another series of tests was initiated in which the odor condition was like or more nearly like that in the gipsy moth tree-banding material. Actual gipsy moth tree-banding material bands were used here, the bands being bridged (covered) with strips of medium-meshed cheesecloth (29 by 34 threads per square inch) of various widths. This combination fulfilled the conditions in an excellent manner; the soft, or viscid, quality of the material was eliminated and the odor apparently was not to any great extent interfered with. This was particularly true in the case of narrow bridges. As in the first series, horizontal bands on white paper, as well as ring bands around peeled vertical stakes, were used. Bands made of ordinary white flour and water (flour paste), of flour and molasses, of molasses alone, and of a commercial sticky tree-banding material were used as checks, and they served very satisfactorily. The ingredients of the gipsy moth tree-banding material could not be used in the making of an odorless band.

The following typical illustrations, Experiments A, B, and C, show the behavior of the caterpillars in this series:

EXPERIMENT A.

(Day bright, fairly warm.)

ELEMENTS.

1. Caterpillar.

Fourth stage; good size for stage, pretty well advanced, pretty well fed, active.

2. **Odorous band** (horizontal).

Gipsy moth tree-banding material, 1½ inches high, 2¼ inches wide, 6 inches long, sides vertical, on a sheet of white paper. Band bridged about in middle with strip of cheesecloth (medium mesh, 29 by 34 threads per square inch) 1 inch wide; cloth fitting closely to band at all points and extending from base of one side to base of opposite side. *Odor of band strong,* irritating writer's nasal membrane at a distance of 2 or more feet.

3. **Strip of stiff white paper** 4 inches long and 1 inch wide.[11]

4. **Paste band** (horizontal).

Flour paste band made of white wheat flour and water, $\frac{1}{20}$ to $\frac{1}{16}$ inch high, 1 inch wide, 3 inches long, on a strip of paper like and of the same dimensions as 3.

TESTS.

The caterpillar was placed on the paper 6 inches from and facing the odorous band (2) at 2.43 p. m. It made straight for the band for about 2 inches, then turned at a diagonal, and continuing in the same general direction went around the end of the band. It approached within 2 inches of the band.

Second placing (as before): The caterpillar turned out of a straight course 3 inches from the band, and when within ½ inch of it veered away still more (now parallel to the band), and, crawling along the band at that distance—its longer hairs brushing the band—it crawled away.

Third placing: The results were similar to those just described.

Fourth placing: The results were similar to those last described.

Fifth placing: The caterpillar turned out of a straight course about 4 inches from the band and went around the end. It approached within 1 inch of the band.

Sixth placing: The caterpillar turned out of a straight course about 4 inches from the band, veered off still more when about 1¾ inches away, and crawled off the sheet of paper parallel to the band at the latter distance.

Seventh placing: The caterpillar moved straight to within about ⅛ inch of the band and hesitated, then continued to the band and apparently touched it—with the mouth parts as well as with the first pair of legs—then turned away. It repeated the procedure soon after on the adjoining side of the bridge, and crawled away.

Eighth placing: The caterpillar paused about ½ inch from the band, then moved closer and swung upon the side with two pairs of legs, but swung off after touching it with its mouth parts, and after another pause backed slowly away. Soon it moved up to the band again and after touching it with its mouth parts turned away nervously. Soon after this it approached close to the band a third time, but turned away apparently without touching it; then crawled away.

Ninth placing: The caterpillar began to turn out of a straight course about 1 inch from the band but turned toward it again when the strip of paper (3) was placed in its way (the paper being held at one end of the longer axis and interposed in the way of the caterpillar with the shorter axis either vertical or at an angle to the horizontal plane of the sheet of white paper on which the caterpillar was crawling). After some hesitation the caterpillar swung upon the side of the band with the first pair of legs, and after touching the band with its mouth parts, swung off and crawled away, crawling across the interposed strip of paper.

Tenth placing: The caterpillar turned at an angle about 3 inches from the band, but veered back somewhat when the strip of paper was placed in its way. It crawled right over the strip of paper, however, when about 1¾ inches from the band, and crawled away, rearing and swinging its head.

Eleventh placing: The caterpillar turned out of a straight course about 3 inches away and stopped for a few seconds when the strip of paper was interposed, then to within ½ inch of the band—guided by means of the strip of paper—and paused. Following another pause, about ¼ inch away, it turned and crawled away over the strip of paper.

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[11] This strip of paper, identical with that on which the paste band was placed, was used, as will be seen below, in the same manner as 4, and was designed as a check upon the latter—to make sure it was the soft and viscid quality of the band that forced the caterpillar on the bridged odorous band rather than the mere object or obstacle placed in its way.

Twelfth placing: The caterpillar turned out of a straight course about 4 inches from the band and stopped for a few seconds when the strip of paper was interposed. Being guided by means of the strip of paper it got to within ½ inch of the band, though constantly trying to turn out of the course. Following a pause it started to turn away again, but the strip of paper arrested it once more. Then it reached the band, but turned away almost immediately. It is impossible to say whether it touched the band. Crawling upon the strip of paper it reached over to the band and got on it with two pairs of legs, but after touching it with its mouth parts turned away. Getting over on the opposite side of the strip of paper, it crawled off and away.

Thirteenth placing: The caterpillar began to turn out of a straight course about 1½ inches from the band, but was arrested by the strip of paper. Following a pause it continued hesitatingly toward the band; when about ½ inch from it (*opposite the bridge*), it crawled up the strip of paper and stretched toward the bare part of the band; it turned away, however, and getting over on the opposite side of the strip of paper it crawled off and away.

Fourteenth placing: The caterpillar started to turn out of its course about 1½ inches from the band after it had stopped and reared and swung its head three or four times, but turned in the direction of the band again when the strip of paper was placed in its way. It stopped again about ½ inch away (*opposite the bridge*), and then turned and crawled upon the strip of paper, the edge of the farther end of which rested against the band at one side of the bridge. On getting closer to the band it swung on the bare part of the latter and apparently touched it twice, then over on the bridged part and swung off almost immediately. It reached forward toward the band again soon after, hesitatingly, but swung away again. It is impossible to say whether it touched. Turning around, it got over on the opposite side of the strip of paper, and finally crawled off and away.

Fifteenth placing: The caterpillar halted and started to turn away when within about 1½ inches (*opposite the bridge*), but turned in the direction of the band again when the strip of paper was interposed. It crawled upon the strip of paper, however, when about ½ inch from the band, and when close to the latter swung upon it (the bare part) and apparently touched it twice lightly, then swung in the opposite direction and landed on the bridged part. After brushing the cloth three times with the first pair of legs and mouth parts it swung over on the bare part again and then back to the strip of paper, then crawled over, hesitatingly, on the opposite side of the latter and crawled down and away.

Sixteenth placing: The caterpillar was stopped from turning out of its course about 2 inches from the band by means of the strip of paper. After some hesitation on its part, during which it started to crawl up the side of the paper rather than to continue in the direction of the band, it started toward the latter, the strip of paper keeping it in its course. It stopped again about 1 inch away (*opposite the bridge*), and on resuming crawled up the strip of paper, but when within ½ inch of the band it stopped once more. Finally it turned away, and after some hesitation got on the opposite side of the paper and crawled off and away.

Seventeenth placing: The caterpillar stopped and turned at a right angle about ½ inch from the band, and turned completely around and started to crawl in the opposite direction when the strip of paper was placed in its path. It turned completely around a second time when the strip of paper was again interposed, but kept right on, crawled upon the strip of paper when it was interposed a third time, and crawled off it and away, after getting, hesitatingly, to the opposite side of the same. (The edge of the farther end of the strip of paper rested against the band each time it was interposed, and always at either of adjoining sides of the bridge, so that up to the time it crawled upon the strip of paper the caterpillar was constantly opposite the bridged portion of the band.)

Eighteenth placing: The caterpillar was placed once more 6 inches from the band[12] (now 4.17 p. m.). It stopped (*opposite the bridge*), reared once or twice, and started to turn out of its straight course, about 1¾ inches away, but turned in the direction of the band again on touching the *paste band* (4) which was placed in its way (horizontally). On reaching the band (which it had approached hesitatingly) it swung upon the bridge with all legs, and from here, after some hesitation, over on the bare part, but swung back to the bridge almost immediately and started slowly upward (the cloth now being thoroughly

[12] Unless otherwise stated or implied, the term "band" refers to the odorous band.

moist and dark, as it had been for some time, saturated with the banding material). Continuing nervously the caterpillar *crossed the band* and crawled away. It got off the bridge, on bare material, once, when on top of the band, but with no more than two pairs of legs, and drew back quickly.

Nineteenth placing: The caterpillar hesitated, reared, and started to turn out of its course about 5½ inches from the band, but on touching the paste band with the first pair of legs, it turned toward the band again. It did not advance, however, but reared, swung its head, and backed up. Then, swinging to one side, it started to crawl out of a straight course again (in the opposite direction from that in the former attempt), but on touching the paste band, which had been placed in its way again, with the first pair of legs at least, it turned once more toward the band and when within about 4½ inches of it, stopped. It now swung its head and turned to one side, and on touching the paste band, which was waiting for it, it swung in the opposite direction and started to turn away still farther from the band. On being interrupted by the paste band again, it turned once more toward the band, and, after some hesitation, started forward. Stopped about ½ inch away (*opposite the bridge*), and after rearing and swinging its head, it turned at a right angle and started crawling parallel to the band. On touching the paste band it turned completely around and started in the opposite direction, but on touching the interposed paste band again it turned in the direction of the band once more. On reaching the band it hesitatingly swung upon the bridged portion, and, after brushing the cloth with its legs, it swung over on the bare part. Then, after touching here once or twice, it swung off the band altogether. It swung back, however, on touching the edge of the paste band, which was waiting for it, then over on the bridge with the first pair of legs, and after touching here with its mouth parts, it swung to the bare part again, then back to the bridged portion, then *up, hesitatingly and nervously, and to the opposite side and down the latter*—4.55 p. m. The caterpillar got off the bridge, on bare material, soon after reaching the top of the band, but with no more than two pairs of legs, and drew back quickly.

EXPERIMENT B.

(Day bright and warm.)

ELEMENTS.

1. **Caterpillar.**

Fifth stage; medium size for stage, fairly well advanced, pretty well fed, active.

2. **Odorous band** (horizontal).

Gipsy moth tree-banding material, as in Experiment A, except ½ inch longer (6½ inches long), *with strong odor*. Bridge moist and dark.

3. **Strip of stiff white paper** 4 inches long and 1 inch wide.

4. **Molasses-flour band** (horizontal).

Molasses-flour mixture (molasses and white wheat flour), $\frac{1}{20}$ inch high, 1 inch wide, 3 inches long, on a strip of paper like and of same dimensions as 3; of about the same consistency as the commercial sticky tree-banding material used in these experiments—somewhat more viscid than the flour paste used in Experiment A.

TESTS.

The caterpillar was placed on the sheet of paper 6 inches from and facing the odorous band (2) at 1.51 p. m. It halted 5½ inches away and reared twice, repeated this movement 4½ inches away, and reared again two or three times at a distance of 4 inches. Then it turned slowly around and crawled away, rearing from time to time as it did so.

The caterpillar was placed again as before. It hesitated and turned its head somewhat from side to side at the start, and stopped and reared three times about 4½ inches away; repeated this at a distance of 3½ inches, and stopped and reared again when within about 2¾ inches. Finally it turned at a right angle and crawled away.

When placed the third time the caterpillar hesitated and reared three distinct times during the first 4 inches of its course toward the band, then turned out of its course somewhat and made its way, hesitatingly, to within ¼ inch. Here it stopped, reared, stretched forward, and brushed the bare part of the band with the first pair of legs and mouth parts. As it turned away the strip

of paper (3) was placed in its way (as in Experiment A), whereupon it turned completely around and began to crawl in the opposite direction (parallel to the band). As the strip of paper was again interposed it stopped altogether (*opposite the bridge*). It backed up finally, turned, and began crawling in the direction away from the band, but as it came close to the strip of paper, which was interposed again, it turned at an angle and started (diagonally) toward the band—the strip of paper guiding it in that general direction. It got upon the strip of paper, however, when about ¾ inch from the band, and soon got off again, but after a pause got on once more and after getting over on the opposite side it crawled off it and away.

At the fourth placing, the caterpillar halted at the very start and had to be prodded (one-half minute later) to get it started again. It responded very slowly. It swung its head slightly, and, turning at right angles, started to crawl away (parallel to the band). It executed another right-angled turn as the strip of paper was placed in its way (now facing away from the band), and still another, when the paper was interposed as it started to crawl directly away from the band, being now parallel to the band. It halted and finally came to rest when the strip of paper was placed in its way a third time. It began to crawl about 1½ minutes later, and as the strip of paper was placed in its way it turned in the direction opposite from the band: very soon after, when the strip of paper was interposed again, it turned at right angles (parallel to the band again) and started to crawl away once more. This time it crawled upon the interposed strip of paper and after crawling on it a short distance toward the band, it got on the opposite side and finally crawled off it, pausing and swinging its head before crawling away. At no time was the caterpillar nearer than 5 inches to the band.

The caterpillar was placed a fifth time. It started to turn out of its course at once and was redirected. Finally, after a good deal of hesitation throughout, it approached within 1½ inches of the band.[13] It turned at right angles here and started crawling parallel to the band, but on getting some of its legs into the molasses-flour band (4), which was placed in its way (horizontally), it turned in the direction opposite from the band; soon after—after touching the molasses-flour band as before—it turned at right angles a third time, and after crawling somewhat (parallel to the band) and touching the interposed molasses-flour band again (three times) it turned once more away from the band. It turned at right angles a fifth time, soon after, because of the molasses-flour band (bringing it parallel to the band again), and on touching the molasses-flour band again it once more turned in the direction of the band. It swung upon the side of the band, on finally reaching it, then down, but swung back on it on touching the molasses-flour band (which was waiting for it at the foot of the band), and landed at the foot of the bridge on finally swinging off a second time. It swung upon the bridge soon after and *crawled up and finally across to the opposite side*—tumbled off in going down latter side. Once, while on top of the band, it got partly off the cloth with some of its legs on bare material, but soon got back.

Placed a sixth time, the caterpillar swung upon the side of the band on finally reaching it (having crawled very slowly and hesitatingly from within about 1 inch), and after lingering a few moments swung down. It swung on and off again shortly afterwards, and after a pause started crawling parallel to the band (at a distance of about ¾ inch); on touching the molasses-flour band, which was placed in its way, it stopped and backed up. On resuming and touching the same a second time it turned at right angles and started crawling directly away from the band. It turned the other way again, however, on touching the molasses-flour band a third time (now parallel to the band again), and on touching it a fourth time it turned and headed directly toward the band. It swung up on the side on reaching it and finally got on with its whole body but soon tumbled off, landing at the foot of the bridge. Then it swung upon the latter (on the side of the band) with some of its legs, and after brushing it with these it swung over on the uncovered part but soon swung back to the cloth, then again to the bare part, then off entirely and started crawling parallel to the band; on touching the molasses-flour band it turned and commenced crawling directly away from the band. It turned at right angles again, however, on touching the molasses-flour band again, twice (now parallel to the band again), and after touching again shortly after, three times in succession, it turned and headed directly toward the band once more. It swung up again

[13] See footnote on p. 9.

on the side of the band and off, slowly, landing again at the foot of the bridge, then up again on the bridge and continuing upward, slowly, along the edge of the cloth, *reached the top; then, slowly, crawled to the opposite side and finally down the latter*—4 p. m. The caterpillar got off the cloth somewhat—on bare material—two or three times, on its way across and down the opposite side. It apparently never got into the molasses-flour band with more than the first pair of legs and often only with the mouth parts.

Similarly, by means of flour-paste and molasses-flour bands, caterpillars were forced to cross even higher gipsy moth tree-banding material bands with narrower bridges—½ inch and ⅛ inch wide.

EXPERIMENT C.

(Day bright and very warm.)

ELEMENTS.

1. **Caterpillar.**

Fifth stage; rather small for the stage, pretty well advanced, well fed.

2. **Odorous band** (ring on stake).

Gipsy moth tree-banding material, good $\frac{5}{16}$ inch thick and 2 inches wide, around a peeled stake 2¼ inches in circumference and 21 inches high, lower plane of band 6 inches from platform to which stake was fixed; lower plane of band quite flat, upper somewhat less so. *With very strong odor.* Band bridged with strip of cheesecloth (medium mesh, 29 by 34 threads per square inch) ⅛ inch wide; cloth fitting closely to band at all points and extending from inner circle of lower plane to inner circle of upper—not extending beyond band. Cloth stained dark by material, and odor over it almost as strong as over unbridged part.

3. **Strip of stiff white paper** 4 inches long and 1 inch wide.

4. **Paste band** (horizontal).

Flour paste made of flour and water, $\frac{1}{20}$ inch high, 1 inch wide, and 3 inches long, on a strip of paper like and of same dimensions as 3; paste somewhat more viscid, or sticky, than gipsy moth tree-banding material.

TESTS.

The caterpillar was placed on the stake 4 inches below and facing the odorous band (2) (11.42 a. m.). It did not begin to crawl until it was prodded, then crawled right up to the band, except that it swung its head when about 2½ inches and again when 2 inches below it, and swung on with the first pair of legs, but after touching it with its mouth parts swung hastily off. This was soon repeated, and shortly after it swung on and off again, after touching it, hesitatingly, with its mouth parts twice. Soon, however, it swung on the band a fourth time, and after touching it as before swung hastily off; then turned downward and crawled down the stake. It rubbed its mouth parts against the stake several times as it swung off the band and turned downward.

The caterpillar was placed again as before and crawled to within about 3 inches below the band, after being redirected upward at the very start, and reared and swung its head violently three times. It repeated this once or twice 2 inches below, thence crawled cautiously and when close to the band stretched upward and got on it with the first pair of legs, but swung down to about ¾ inch below, after touching it with the mouth parts twice in quick succession. Then, after circling nearly one-half the stake, it reached the band again and swung on again, hesitatingly, with the first pair of legs, but swung down again quickly after touching it again with the mouth parts; then turned and crawled slowly down the stake.

Placed a third time, the caterpillar swung its head and hesitated at the very start, but continued upward, swinging its head frequently, and when about 1½ inches below the band slowed down still more and became still more hesitant. Finally, when close to the band, it reached up to it with the first pair of legs, and after touching it twice in quick succession with the mouth parts also, it turned away. Soon afterwards it swung on a second time with the first pair of legs, hesitatingly (near the edge of the bridge), and after touching it with the mouth parts swung over on the bridge, then off the band altogether. After a pause it swung on a third time, on the bridge, thence over on bare material; after touching the latter with the mouth parts it swung off altogether and turning around started downward. It paused about ⅛ inch below the band when

the strip of paper (3) was placed in its way, horizontally (in horizontal relation to stake), then got on the paper and finally on the writer's hand and arm.

The caterpillar was placed a fourth time. It began rearing and swinging its head quite violently when about 3 inches below the band, and at 2 inches below reared and swung its head so violently as to turn almost completely around. It did not advance, however, on swinging back to its former position on the stake; instead it reared, swung round as before, and started downward, the interposed strip of paper failing to check it or to cause it to turn upward again.

The caterpillar was placed a fifth time. It hesitated noticeably at the start and swung its head two or three times when about 1 inch from the band, thence crawled slowly and when close to the band reached up and touched it with the first pair of legs and mouth parts, following which it swung down. This was repeated soon after, and again soon after that, touching it three times instead of once. After a pause about 1 inch below the band, it got to the band again, slowly, and swinging on as before touched it twice, then swung down and crawled downward, coming to rest finally on the strip of paper, which was placed in its way (about 3 inches below the band), and which it approached without hesitation. On becoming active soon afterwards it turned around, got to the stake again, and started to crawl up it, but swung down almost at once, and, turning round, crawled the full length of the strip of paper to the writer's hand.

When placed a sixth time the caterpillar hesitated at the start, crawled up slowly, and stopped altogether about 1 inch below the band (*opposite the bridge*). On resuming soon after (at a diagonal), it got to the band (bare part) and swung up toward it but swung quickly down—touching it lightly if at all. Then it got around nearer to the bridged part and swung up, close to the latter, with the first pair of legs, and after touching the bare material with its mouth parts swung over on the bridge. Touching here (on the cloth) once or twice, it swung off the band altogether. It swung back, however, on the bridge, and, continuing upward, along the edge, *crawled up and across*. (The cloth was moist—saturated—and the difference in odor between the bridged and bare parts of the band was slight.)

The caterpillar was placed a seventh time. It moved up slowly, and when about ¾ inch below the band [14] reared and swung the fore part of its body three times, seemingly as if it might turn downward each time. This was repeated about ¼ inch farther up; then the caterpillar crawled hesitatingly to the band and reached up with the first pair of legs, but on touching it also with its mouth parts it swung down quickly and turned downward. It turned upward again, however, after getting twice into the flour-paste band (4) (which was placed in its way in the same manner as 3) with its mouth parts—for several seconds the first time and for two seconds the next—but soon turned downward and on getting into the paste band again, with the first pair of legs as well as with the mouth parts, it turned upward once more. After two or three pauses and some swinging of the head, it reached the band (on the opposite side from the bridge). It swung on with the first pair of legs, but on touching it with the mouth parts it swung quickly down again. It swung on and off, as above, at short intervals, at different points on the band, six more times—touching it thrice, several times before swinging down—following which, the eighth time, it swung upon the bridged part, and in this instance *it continued upward—hesitatingly, and so crawled across*, continuing to the top of the stake (1.13 p. m.). The caterpillar got off the cloth slightly, on bare banding material, at least four times, twice on each side, while crossing.

Previous to this, caterpillars were, in the same manner, compelled to cross similar bands, with bridges respectively 1 inch, ¾ inch, and ½ inch wide.

SERIES III.

Finally, in a third and last series, caterpillars in several instances were forced, by means of flour-paste (flour and water) and flour-molasses bands, into and on much higher (higher than themselves), and in some cases wider, naked (horizontal) gipsy moth tree-banding material bands; and in two cases where the banding material was rather firm the caterpillars actually crossed the bands. On the other hand, efforts in the reverse process, as a check measure, to compel

[14] See footnote on p. 9.

caterpillars to cross paste bands by means of interposed gipsy moth tree-banding material bands were unsuccessful. In one instance, indeed, the caterpillar finally crossed the gipsy moth tree-banding material band. In the latter instances the two types of bands were of the same dimensions as regards height and width; about $\frac{1}{16}$ inch and 1 inch, respectively.

SUMMARY AND CONCLUSIONS.

That the two factors of (1) odor, and (2) soft and semiviscid condition, operate together in enabling the gipsy moth tree-banding material to halt the caterpillars in their efforts to ascend to the foliage, was clearly demonstrated by the qualitative tests described in this paper. The first series, in which the solid odorous bands were used, could not be considered conclusive, for physical or technical reasons (p. 7), but it indicated clearly that the first element, namely, odor, exercises at least a restraining influence. The second series, in which bands made of actual gipsy moth tree-banding material were used, demonstrated satisfactorily that the soft and semiviscid, or viscous, condition of the material is the basic or primary factor. The odor restrained, indeed, but when acting alone did not completely check; whatever "dislike" or "fear" it inspired was overcome sooner or later.[15] This series approximated closely to actual conditions, especially in the case of the narrowly bridged bands, in which the odor, after the strips of cloth became saturated with the material, was but little if at all interfered with or masked; indeed, the total odor emitted by some of these bands was far greater than would have been emitted, under the same conditions, by the smaller-sized "standard" band,[16] the odor being strong enough in the warm and rather confined atmosphere of the laboratory to irritate to a considerable degree, at a distance of about 2 feet, the nasal membrane of the writer. The various check bands used, namely, flour paste, flour-molasses, molasses, and also a commercial sticky tree-banding material, served very well, and if the last three were somewhat more viscid or "gluey" than the bands made from the gipsy moth tree-banding material, this fact was offset by the greater odor given off by the large size of the latter bands.

The caterpillars, it should be added, seemed to "dislike" or "fear" the odorless and nonirritating check bands in proportion as they were viscid, or "sticky," and they reacted to these very often, especially to the more viscid, fully as promptly as to the gipsy moth tree-banding material bands. This fact is further evidence of the importance of the viscid factor in the banding material, and is of value, obviously, in the elaboration of an efficient barrier band not only against gipsy moth caterpillars but also against any species of similar behavior. An illustration of the practical operation of this fact is perhaps seen in the efficiency of newly applied or newly combed bands of a commercial sticky tree-banding material, the odor or exhalation of which is weaker and otherwise less repellent than that of the gipsy moth tree-banding material, especially on warm days. An atmosphere consisting of, or heavily charged with, the exhalation or volatilized portion of the latter material, as in a container, will disable a cater-

[15] In nature, in response to such stimuli as light (positive heliotropism), and more especially, hunger. Such "fear" would probably be overcome speedily.

[16] See footnote on p. 4.

pillar in a comparatively short time, even on days of moderate temperature. In case of actual contact, however, injury may be from an additional source—from the penetration of the material through the skin.[17]

The irritation or "burning" caused by the gipsy moth tree-banding material, as a result of contact, may therefore aid in repelling the caterpillars, especially if contact is with delicate and sensitive parts, such as the mouth parts. Again, since the latter are organs of taste, and in certain adult Lepidoptera at least the tarsi also act as such (*7, p. 202–203; 8, p. 80–81*), the sense of taste may be a factor. These considerations, however, should not affect the conclusion that *the viscous, or physical, condition is the more important, or primary, barrier factor in the band* as it ordinarily functions, which may be said to have been clearly demonstrated and which is borne out, so far as can be judged, by observations in the field. Indeed, since the head, the head appendages, and the legs of caterpillars seem to be well adapted for receiving olfactory stimuli (*6, p. 76*), we may perhaps also see in the rather rapid withdrawal of such parts the action of odor and thus additional evidence, or a confirmation of the other and more obvious conclusion, namely, that the two factors, i. e., the soft or semiviscid or viscous condition of the material, and the odor, or exhalation, of the material, are the chief factors which make the gipsy moth tree-banding material the efficient barrier that it is.

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[17] Severe "burning" may result if the material is placed upon and is allowed to penetrate the human skin.

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